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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : G09G	A2	(11) International Publication Number: WO 97/31359 (43) International Publication Date: 28 August 1997 (28.08.97)

(21) International Application Number: PCT/IB97/00129

(22) International Filing Date: 14 February 1997 (14.02.97)

(30) Priority Data:
96200456.0 22 February 1996 (22.02.96) EP
(34) Countries for which the regional or international application was filed: NL et al.

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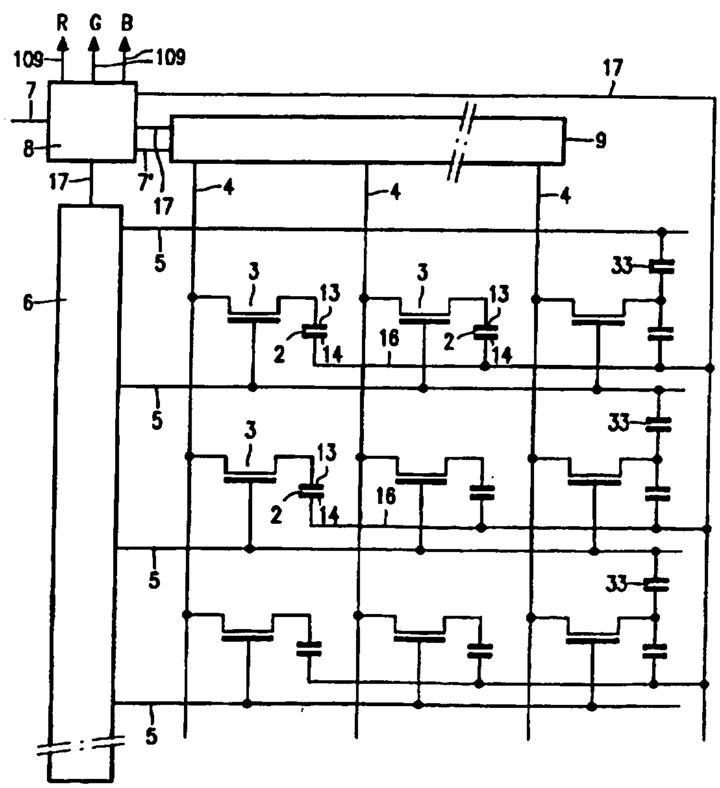
(81) Designated States: JP, KR, European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published
Without international search report and to be republished upon receipt of that report.

(54) Title: DISPLAY DEVICE

(57) Abstract

(Color) display device based on Deformed Helix Ferroelectric liquid-crystal display devices, and display devices based on ferroelectric liquid-crystal material with twisted smectic structure, monostable ferroelectric liquid-crystal material, electroclinic smectic A liquid-crystal material and anti-ferroelectric liquid-crystal material, in which the memory effect, for example, in video applications is eliminated by previously and simultaneously a group of rows. If all rows are previously reset at the same time, the display device can very suitably be used for a projection display device of the field-sequential-color type.



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Display device.

The invention relates to a color display device comprising an illumination system for generating light beams of different colors within a field time, and comprising a drive device for addressing the light-switching device to provide picture information related to the color of the relevant light beam in order to modulate this light beam with the picture information, which light-switching device includes a matrix of pixels which can be driven via active switching elements, and during the period when a light beam of a given color is provided, the drive device causes the pixels to switch to the transmission value of the associated color. Such devices are used, in particular, in projection systems for video applications.

The invention also relates to a display device comprising a first substrate and a second substrate having a matrix of liquid-crystal display elements which are arranged in rows and columns between said first and second substrates, each display element being connected to a column electrode or to a row electrode via an active switching element, and the display device comprising means for bringing display elements to an extreme optical transmission state, prior to selection, by means of an auxiliary signal.

In a color display device of the type mentioned in the opening paragraph, which is used for projection, a color picture is obtained by rapidly generating a succession of red, green and blue sub-pictures by driving a twisted nematic liquid-crystal panel with the information associated with a given color and, subsequently, projecting the sub-picture thus obtained. As in this type of projection devices the information changes at a much higher rate than in the customary display devices (the frame frequency is a factor of 3 higher), the use of twisted nematic liquid-crystal material may cause problems. If use is made of twisted nematic materials, the capacitance of a pixel is voltage-dependent, which is difficult to correct because it cannot be corrected uniformly. In addition, these materials generally react slowly; since each pixel must successively display, within one frame period, the information associated with various colors, the voltage across a pixel cannot relax to a final value within a specific amount of time (for example one or two frame periods). The information associated with a different color can differ so much from that associated with the preceding color, that the preceding information value influences the final value of the (color) signal to

be written (memory effect from (sub-)picture to (sub-)picture).

It is an object of the invention to provide, inter alia, a color display device of the type mentioned in the opening paragraph, in which the above-mentioned influence is practically absent. The invention also aims at providing such a device in which the light-switching device reacts rapidly and in which little, if any, consideration has to be given to the influence of the pixel capacitance when the drive signals are supplied.

To this end, a color display device in accordance with the invention is characterized in that the light-switching device comprises a liquid-crystal display device having, between a first substrate and a second substrate, a liquid-crystal material of the group of smectic liquid-crystal materials, which include ferroelectric liquid-crystal material with deformable helix, ferroelectric liquid-crystal material with twisted smectic structure, monostable ferroelectric liquid-crystal material, electroclinic smectic A liquid-crystal material and anti-ferroelectric liquid-crystal material, and a matrix of electro-optic display elements arranged in rows and columns, each electro-optic display element being connected to a column electrode or a row electrode via an active switching element, and the display device comprising means to bring a plurality of successive rows of display elements to an extreme optical transmission state, prior to selection, by means of an auxiliary signal.

In general, a ferroelectric liquid-crystal material with a deformed helix is to be understood to mean a ferroelectric liquid-crystal material with a natural helix whose pitch is smaller than the wavelength of visible light (up to approximately 400 nm). An electric field at right angles to the axis of the helix causes deformation of this helix, which results in a rotation of the optical axis. This leads to an increase in transmission, for positive as well as negative fields, between crossed polarizers of which one polarizer extends parallel to the axis of the helix.

Just like the other materials mentioned hereinabove, the ferroelectric liquid-crystal material with a deformed helix has a high polarization in the fully driven state. If they are provided between a polarizer and an analyzer, the above-mentioned materials have another characteristic in common, namely that at a specific angle of the polarizer and the analyzer, said materials can switch between substantially light-transmissive and substantially opaque.

In this case, positive and negative voltages generally exhibit a symmetrical voltage/transmission curve. Examples of such effects are described in

- J.S. Patel: "Ferroelectric Liquid Crystal Modulator using Twisted Smectic Structure", Appl. Phys. Lett. Vol. 60(3) pp. 280-282 (1992)

- H. Okada et al: "New Display Mode of Ferroelectric Liquid Crystals with Large Tilt Angle", Ferroelectrics Vol. 149, 171-181 (1993),
- D.M. Walba el al: High Performance Electroclinic Materials", Ferroelectrics Vol. 148, 435-442 (1993).

Yet another example is the anti-ferroelectric liquid-crystal effect, as described, for example, in Asia Display '95, pp. 61-64.

The use of a ferroelectric liquid-crystal material having a deformable helix is described in "A Full-Color DHF-AMLCD with Wide Viewing Angle" in SID 94 DIGEST pp. 430-433. According to said article, the use of devices with DHFLC-material (Deformed Helix Ferroelectric Liquid Crystal) is advantageous as compared to so-called SSFLC-devices (Surface Stabilized Ferroelectric Liquid Crystal) because of the absence of multidomains, while a more continuous change of the transmission/voltage characteristic enables a better realization of grey scales to be achieved. Despite the high switching rate of the mixture used in the display device, the field frequency remains too low for video applications (NTSC or PAL). Moreover, in the device described in said article so-called "image sticking" occurs.

The invention is based on the recognition that, unlike known (ferroelectric) liquid-crystal display devices, upon application of a voltage across a pixel, the spontaneous polarization of DHFLC materials plays such an important part that either it requires such a long time that the display device as a whole becomes too slow or the pixel does not always receive the desired charge and the associated transmission value. In the last-mentioned article, it is proposed to bring a row of display elements to an extreme optical transmission state by means of an auxiliary voltage (reset), prior to selection, but also in this case the pixel does not always receive the desired charge owing to the great importance of the spontaneous polarization, so that incomplete reset occurs. As the charge (and hence the transmission value) across the pixel is undefined again after this reset, the data signal provided in a subsequent selection will not lead to the intended final value of the charge (and hence of the transmission value) across the pixel, etc. Even in the case of an identical grey level of the pixel to be written over a period covering a plurality of field times, it may take a number of field times to eliminate this "memory effect".

In a display device in accordance with the invention, the "memory effect" is eliminated at least substantially by bringing a plurality of successive rows of display elements to an extreme optical transmission state,
prior to selection, by means of an auxiliary signal. The duration and the magnitude of the relevant reset pulse are sufficient to compensate for the effects caused by spontaneous

polarization. Particularly in a device which is used for projection, it is advantageous to previously bring all rows in an extreme optical state; after the subsequent writing of the video information of one of the constituent (color) pictures, the illumination source with the relevant color is activated.

A further embodiment of a display device in accordance with the invention is characterized in that the drive device comprises means for correcting, within each group of successive rows to be brought to an extreme optical transmission state, drive voltages on the electrodes by means of correction signals so that the average amplitude of the voltage on the display elements increases upon selection of a next row within the group.

If the active switching element is, for example, a TFT, each pixel can be provided with an additional capacitor. The charge stored on the additional capacitor during the selection period (which can be much shorter now) also determines the charge across the pixel (and hence the polarization).

Another embodiment is characterized in that the active switching element is a TFT on the first substrate, and the drive device includes means enabling the voltage of a counter electrode situated on the second substrate to be inverted every drive period. In this case, lower drive voltages and hence cheaper drive circuits are sufficient.

If the display device is constructed as a reflective display device, one of the substrates may be made from silicon, and the switching elements and any drive electronics are integrated in the substrate (the TFTs are situated, for example, below the picture electrodes).

These and other aspects of the invention will be apparent from and elucidated with reference to the embodiments described hereinafter.

In the drawings:

Fig. 1 schematically shows a color display device in accordance with the invention,

Fig. 2 schematically shows an electrical equivalent circuit diagram of a part of a display device for use in a color display device in accordance with the invention,

Fig. 3 schematically shows a part of the drive circuit of the device in accordance with Fig. 1,

Fig. 4 schematically shows a cross-sectional view of the device in accordance with Fig. 3,

Fig. 5 schematically shows the position of the polarizers with respect to the helix (Fig. 5^a) and a transmission/voltage characteristic (Fig. 5^b) of a device in accordance with the invention,

Fig. 6 schematically shows a number of different voltage curves and the associated polarization, transmission and illumination for the device shown in Figs. 1 and 2, while Fig. 7 schematically shows another color-display device in accordance with the invention, and

Fig. 8 schematically shows a number of different voltage curves for the device shown in Fig. 7.

The figures are schematic and not drawn to scale; corresponding elements generally bear the same reference numerals.

Fig. 1 schematically shows a color display device 100 in accordance with the invention, which comprises an illumination system having three switchable light sources 101 of red, green and blue light (R, G, B) as well as a color-combining element 102 (for example a dichroic cross), which reflects or passes the light originating from the light sources 102. The device further comprises a display device or a light-switching device (light valve) 106, which is driven, for example, by means of video signals. This display device modulates the light in accordance with the input signals, whereafter the modulated, successive pictures of different color are projected by the projection lens 107 on a suitable surface, such as a projection screen 108.

In this example, the light-switching device 106 comprises a liquid-crystal device with a ferroelectric material having a deformable helix or a similar material. Such a device is schematically shown in Fig. 2.

Fig. 2 shows an electrical equivalent circuit diagram of a part of a display device 1. This device includes a matrix of pixels 2 which are arranged in rows and columns. In this example, the pixels 2 are connected to column electrodes or data electrodes 4 by means of three-pole switches, in this example TFT transistors 3. A row of pixels is selected via row or selection electrodes 5 which select the relevant row via the gate electrodes of the TFTs. The row electrodes 5 are successively selected by means of a multiplex circuit 6.

Incoming data signals or (video) information 7 are processed in a processing/drive unit 8 and stored in a data register 9. The voltages provided by the data register 9 cover a voltage range which is sufficient to set the desired range of grey levels. Pixels 2, in this case represented by capacitors, are charged positively or negatively via the TFTs 3 as a result of the fact that, during selection, the picture electrodes 13 take over the

voltage from the column electrodes. In this example, the picture electrodes 14 form a common counter electrode, which is referenced 16. Synchronization of said picture electrodes takes place via drive lines 17.

By using active switching elements, it is precluded that signals on the column electrodes intended for other pixels affect the setting of the voltage across the pixels before these pixels are selected again (in a subsequent (sub-)field). In this example, the drive unit 8 comprises a converter 8' (Fig. 3) which converts the incoming signal 7 to red, green and blue sub-pictures (or sub-fields) which are stored in the data register via the connection 7'. The converter 8' generates a trigger signal which activates the red, blue or green lamp 101 via the drive lines 109 as soon as the sub-picture of the relevant color has been written.

Fig. 4 is a schematic, cross-sectional view of the device shown in Fig. 2. On a first substrate 18, there are row or selection electrodes (not shown), as well as column or data electrodes 4 and picture electrodes 13, which are made, in this example, of a transparent, conductive material such as indium-tin oxide, which electrodes are connected to the column electrodes 4 via the TFTs 3 by means of (schematically shown) connections 19.

A counter electrode 14, 16 is situated on a second substrate 22. Both substrates are further covered with orienting layers 24, while a ferroelectric liquid-crystal material with a deformable helix 25 is situated between the substrates. Any spacers and the sealing edge are not shown. The device further comprises a first polarizer 20 and a second polarizer or analyzer 21 whose polarization axes intersect at right angles.

Fig. 5 schematically shows a transmission/voltage characteristic (Fig. 5^b) of a cell in such a device, in which, the axis of the helix (and hence the optical axis 28) of the DHFLC material is chosen to extend parallel to one of the polarizers (see Fig. 5^a), in the absence of the electric field, the so-called symmetric mode. As a result of an applied electric voltage across the cell, the molecules try to direct their spontaneous polarization towards the associated field, which leads, between crossed polarizers with the axis of the helix extending parallel to one of the polarizers, to a transmission/voltage characteristic which exhibits an increase in transmission for positive and negative voltages as the voltage increases (Fig. 5^b). However, the invention can also be applied in the so-called asymmetric mode in which the crossed polarizers are rotated relative to the substrates in such a manner that the optical axis of the helix of the DHFLC material coincides in the driven state with one of the directions of polarization.

Fig. 6 schematically shows a time diagram for use in the device shown in Figs. 1, 2 and 3 with a part of the drive device 8. A frame time t_f comprises three sub-frame

times t_{sf}. In this example, t_f is, for example, approximately 16.6 msec and t_{sf} is approximately 5.5 msec. Each one of the three sub-frame times comprises a reset portion 31, a write portion 32 and an illumination portion 33.

Fig. 6^a and Fig. 6^b show, respectively, the selection pulses for two successive rows n and n+1 of display elements n and n+1 during a frame time t_f which comprises three sub-frame times t_{sf}. During the reset part 31, all rows receive a reset pulse 34, while the column electrodes receive, for example, a voltage of 0 V (Fig. 6d). For this purpose, the amplitude and duration of the reset pulse are chosen to be such that all elements of the relevant (in this case, red) sub-picture are brought to an extreme state which, in this case, is completely opaque. During the subsequent write part 32, all rows are successively selected by means of selection pulses 35, while a video signal or other information is presented to the column electrodes. Fig. 6^e shows the voltage across a pixel, and Fig. 6^f shows the associated transmission T. As a result of the reset action, in which the pixels of the entire display device receive a voltage of 0 V (and hence zero transmission), all "memory effects" are eliminated. The presence of the auxiliary capacitors 33 (shown for only one column in Fig. 2) causes the voltage loss across the pixels to be reduced. The auxiliary capacitors have a capacitance value which is approximately 10 times (5 to 20) that of a pixel. If the red sub-picture has been completely written, the red lamp 101 is activated (reference numeral 36 in Fig. 6^g) via the drive line 109(R), so that the red sub-picture is projected. Subsequently, the display device is reset again in the same manner as described hereinabove, and, subsequently, the green sub-picture is written and (after activation of the green lamp 109(G) projected, etc. An alternating voltage V_{com} is applied (during selection) to counter electrode 16 (Fig. 6^c), so that the amplitude of the column voltages can be limited.

In the above example, all rows of the display device were reset simultaneously, however, this is not absolutely necessary. It is alternatively possible to reset successive groups of (for example 8) rows, whereafter said rows are written again. This way of writing can also be used in direct-vision display devices.

Fig. 7 shows such a device for projection, which in this case, however, is based on a reflective display device 106'. This reflective display device comprises a dichroic mirror 103, whereas analyzer 105 and polarizer 104 do not form part of said display device 106'. Display device 106' is reflective and includes for this purpose, for example, a silicon substrate having reflective picture electrodes, while the switching elements (transistors) and, if necessary, also drive electronics are integrated in the silicon substrate. The other reference numerals have the same meaning as in Fig. 1.

Fig. 8 schematically shows a time diagram for use in the device shown in Fig. 7. In a sub-frame time t_{sf}, groups of n rows (in this example n = 8) are successively reset during a reset part and then selected.

Figs. 8^{a-c} and Figs. $8^{g,h}$ show, respectively, a number of selection pulses for two successive blocks of rows of display elements. During the reset part, all n rows of a block are reset by means of a reset pulse 34, while a voltage, for example, of 0 V is applied to the column electrodes (Fig. 8^{d}). To this end, the reset pulse has such a duration that all elements of the relevant group of rows are brought to an extreme state, which in this case is completely opaque. During the subsequent selection, all rows of a group are successively selected by means of selection pulses 35, while a video signal or other information is presented to the column electrodes. Figs. $8^{e,f}$ and Figs. $8^{i,j}$ show the voltage across pixels in the rows 1 and n of the blocks 1 and 2. As a result of the reset action, in which the pixels of a block always receive a voltage of 0 V (and hence zero transmission), all "memory effects" are eliminated again. As a result, upon selection, a pixel immediately receives the desired voltage (and transmission value), so that aftereffects do not take place.

The presence of the auxiliary capacitors 33 (shown for only one column in Fig. 2) causes the voltage loss across the pixels to be reduced. The auxiliary capacitors have a capacitance value which is approximately 10 times (5 to 20) that of a pixel. To preclude DC effects, the data voltages are presented in inverted order in a subsequent sub-picture (field).

After the re-setting operation, the proper pixel voltage is successively applied to the rows of pixels within one block. The first row of each block retains this voltage (apart from leakage losses etc.) for a period of time which is equal to a sub-frame time minus the reset time (8 line times in the above example), whereafter this row is selected again and provided with the proper information. The second row of each block retains the pixel voltage for a period of time which is equal to a sub-frame time minus the reset time (8 line times) plus 1 line time, i.e. in total 9 line times, whereafter this row is reselected and provided with the proper information. The eighth row of each block retains the pixel voltage for a period of time which is equal to a sub-frame time minus the reset time (8 line times) plus 7 line times, i.e. in total 15 line times, whereafter this row is reselected and provided with the proper information.

Driving of different rows with the proper information of unequal duration may become visible as a difference in average transmission. This can be advantageously precluded by adapting, within a block, the row or column voltage at every subsequent

selection of a row within said block, in such a manner that the transmission is set at a slightly higher level. For example, if the voltage on the common counter electrode is 0 V, in the case of the above-mentioned division in blocks of 8 rows, the amplitude of the column voltage during writing of the row selected as the second one, is increased relative to the amplitude of the column voltage during writing of the row selected as the first one, the amplitude of the column voltage during writing of the row selected as the third one is increased relative to the amplitude of the column voltage during writing of the row selected as the second one, etc.

If use is made of two-pole switching elements, the amplitudes of the column voltages and selection voltages are adapted in such a manner that differences in pixel voltage are corrected.

Of course, the invention is not limited to the exemplary embodiments described herein, and within the scope of the invention, many variations are possible. For example, in Fig. 8, transmissive display devices can be used instead of reflective display devices. The invention can also be used in direct-vision display devices.

In summary, in the case of Deformed Helix Ferroelectric liquid-crystal display devices and display devices based on ferroelectric liquid-crystal material having a twisted smectic structure, monostable ferroelectric liquid-crystal material, electroclinic smectic A liquid-crystal material and anti-ferroelectric liquid-crystal material, the invention enables the memory effect, for example, in video applications to be eliminated by previously resetting a group of rows. If all rows are previously reset, the display device can very suitably be used in a projection display device of the field-sequential-color type.

CLAIMS:

1. A color display device comprising an illumination system for generating light beams of different colors within a field time, and comprising a drive device for addressing the light-switching device to provide picture information related to the color of the relevant light beam in order to modulate this light beam with the picture information, which light-switching device includes a matrix of pixels which can be driven via active switching elements, and in which prior to the period when a light beam of a given color is provided, the drive device causes the pixels to switch to the transmission value of the associated color, characterized in that the light-switching device comprises a liquid-crystal display device having, between a first substrate and a second substrate, a liquid-crystal material of the group of smectic liquid-crystal materials, which include ferroelectric liquid-crystal material with deformable helix, ferroelectric liquid-crystal material with twisted smectic structure, monostable ferroelectric liquid-crystal material, electroclinic smectic A liquid-crystal material and anti-ferroelectric liquid-crystal material, and a matrix of electro-optic display elements arranged in rows and columns, each electro-optic display element being connected to a column electrode or a row electrode via an active switching element, and the display device comprising means to simultaneously bring a group of successive rows of display elements to an extreme optical transmission state, prior to selection, by means of an auxiliary signal.

2. A color-display device as claimed in Claim 1, characterized in that the drive device comprises means for bringing all rows of display elements to an extreme optical transmission state, prior to selection, by means of an auxiliary signal.

3. A color-display device as claimed in Claim 1, characterized in that the drive device comprises means for correcting, within each group of successive rows to be brought to an extreme optical transmission state, drive voltages on the electrodes by means of correction signals so that the average amplitude of the voltage on the display elements increases upon selection of a next row within the group.

4. A color-display device as claimed in any one of Claims 1 to 3, characterized in that the active switching element is a TFT on the first substrate, and the drive device includes means enabling the voltage of a counter electrode situated on the second substrate to be inverted every drive period.

5. A display device comprising a first substrate and a second substrate having a matrix of liquid-crystal display elements which are arranged in rows and columns between said first and second substrates, each display element being connected to a column electrode or to a row electrode via an active switching element, and the display device comprising means for bringing display elements to an extreme optical transmission state, prior to selection, by means of an auxiliary signal, characterized in that the display device contains a liquid-crystal material of the smectic liquid-crystal material-containing group formed by ferroelectric liquid-crystal material with deformable helix, ferroelectric liquid-crystal material with a twisted smectic structure, monostable ferroelectric liquid-crystal material, electroclinic smectic A liquid-crystal material and anti-ferroelectric liquid-crystal material, and the display device includes a drive device having means for simultaneously bringing a group of the rows of display elements comprising a plurality of successive rows to an extreme optical transmission state, prior to selection, by means of an auxiliary signal.

6. A display device as claimed in Claim 5, characterized in that the drive device comprises means for correcting, within each group of successive rows to be brought to an extreme optical transmission state, drive voltages on the electrodes by means of correction signals, in such a manner that the average amplitude of the voltage on the display element increases within the group upon selection of a subsequent row.

7. A display device as claimed in Claim 5 or 6, characterized in that the active switching element is a TFT on the first substrate, and the drive device comprises means enabling the voltage of a counter electrode situated on the second substrate to be inverted every drive period.

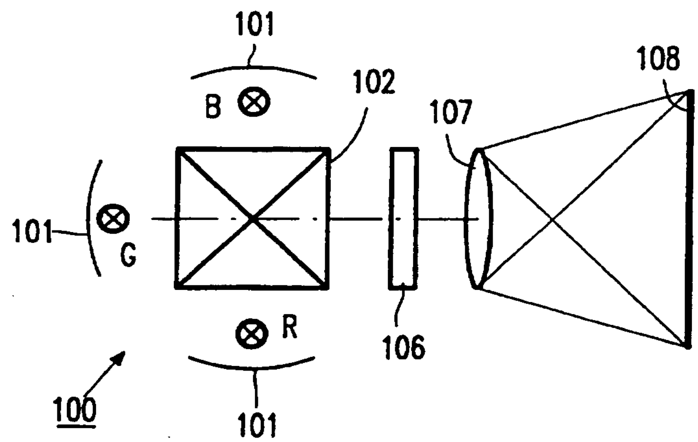

FIG. 1

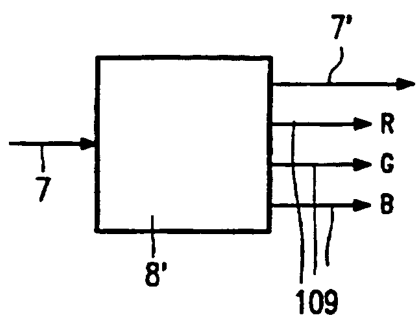

FIG. 3

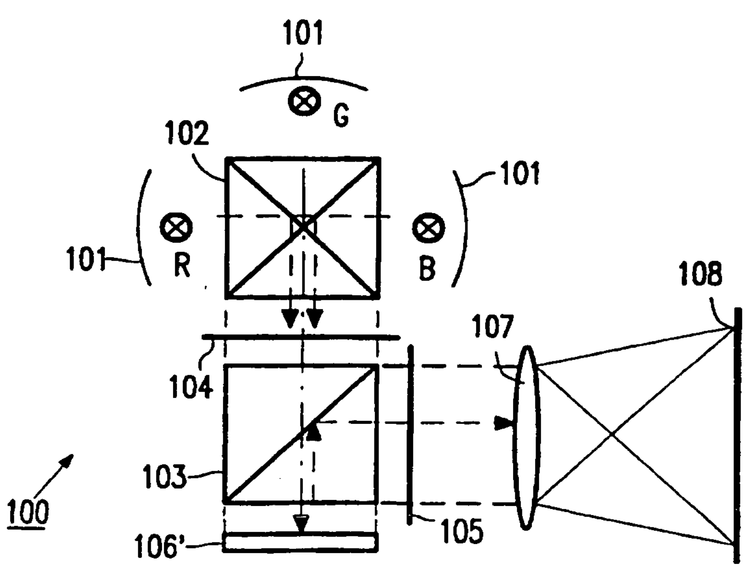

FIG. 7

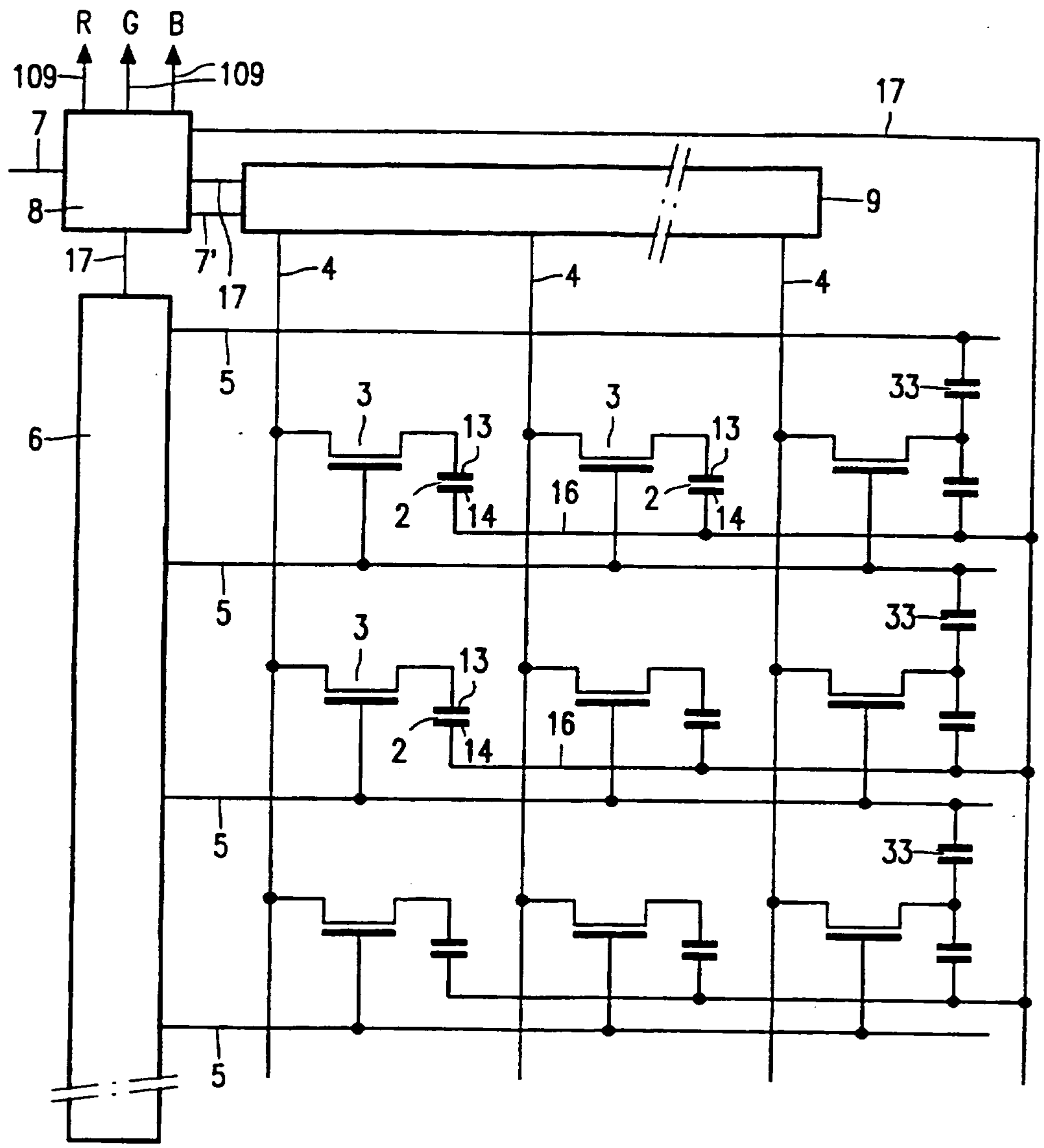
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FIG. 2

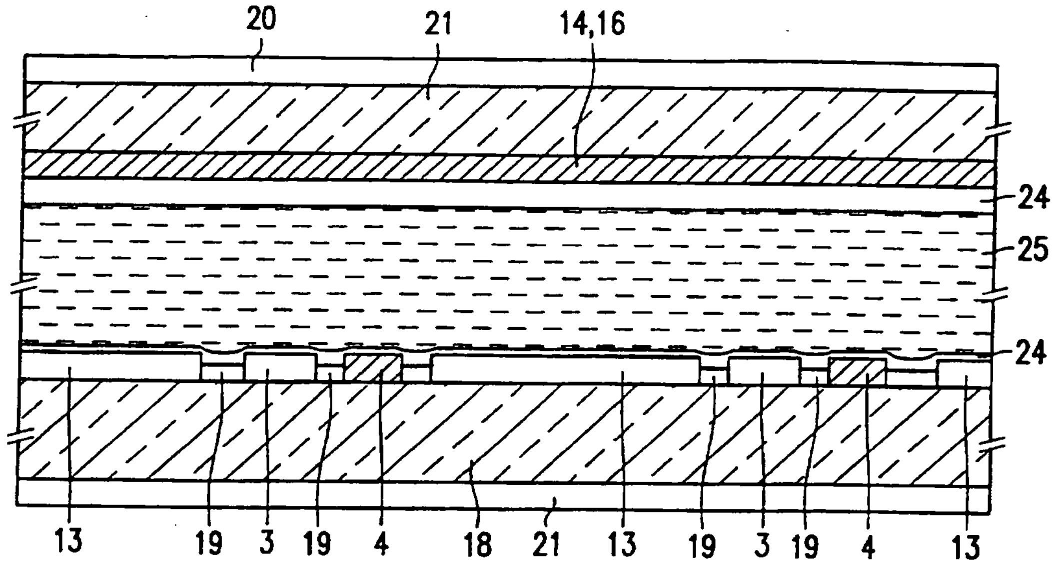

FIG. 4

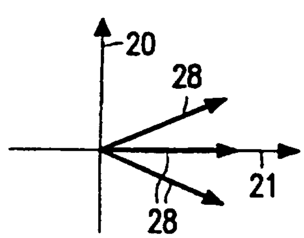

FIG. 5a

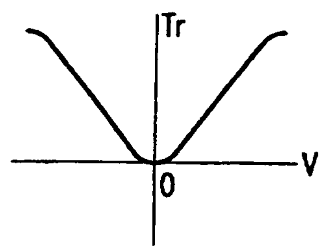

FIG. 5b

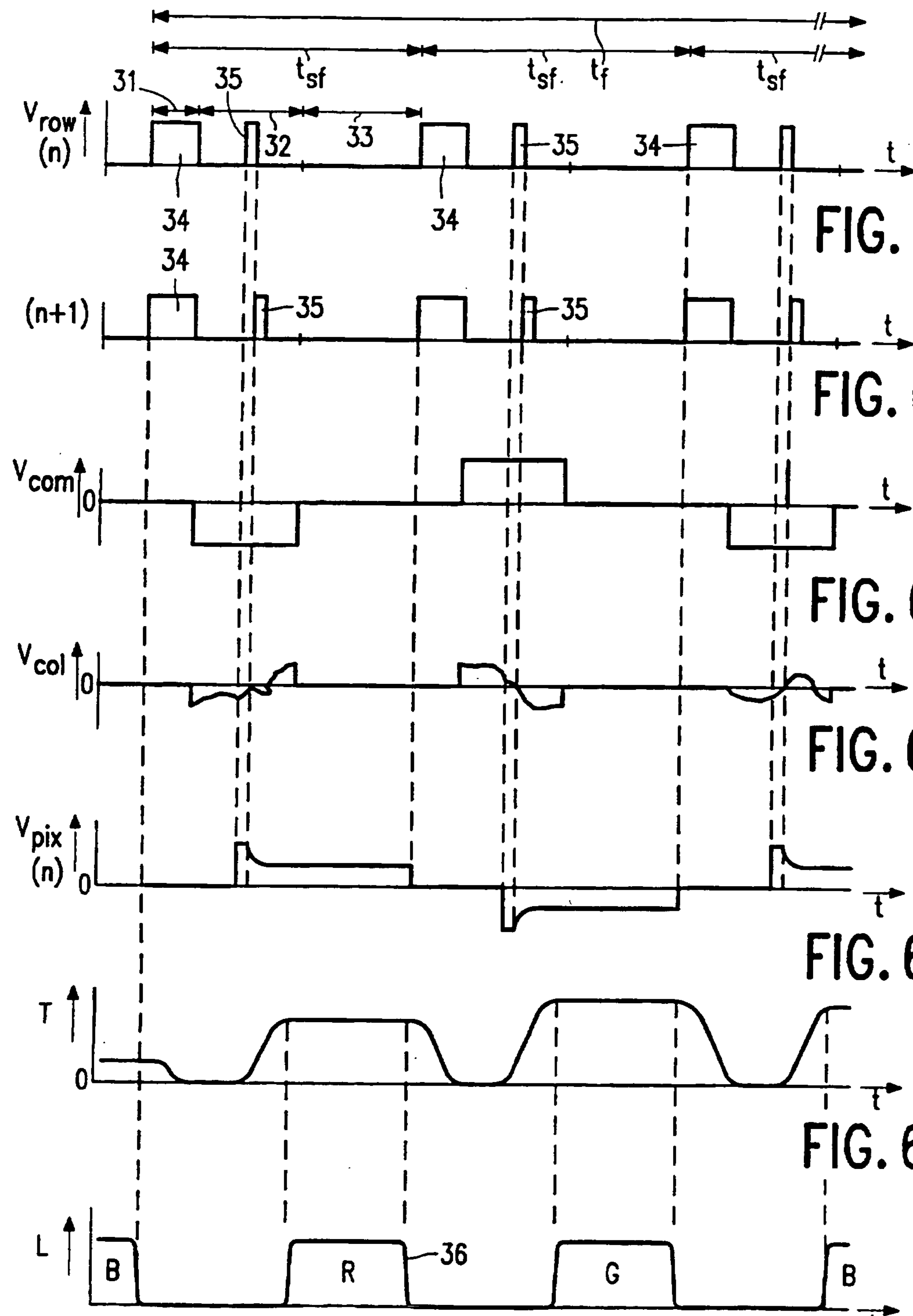

FIG. 6a

FIG. 6b

FIG. 6c

FIG. 6d

FIG. 6e

FIG. 6f

FIG. 6g

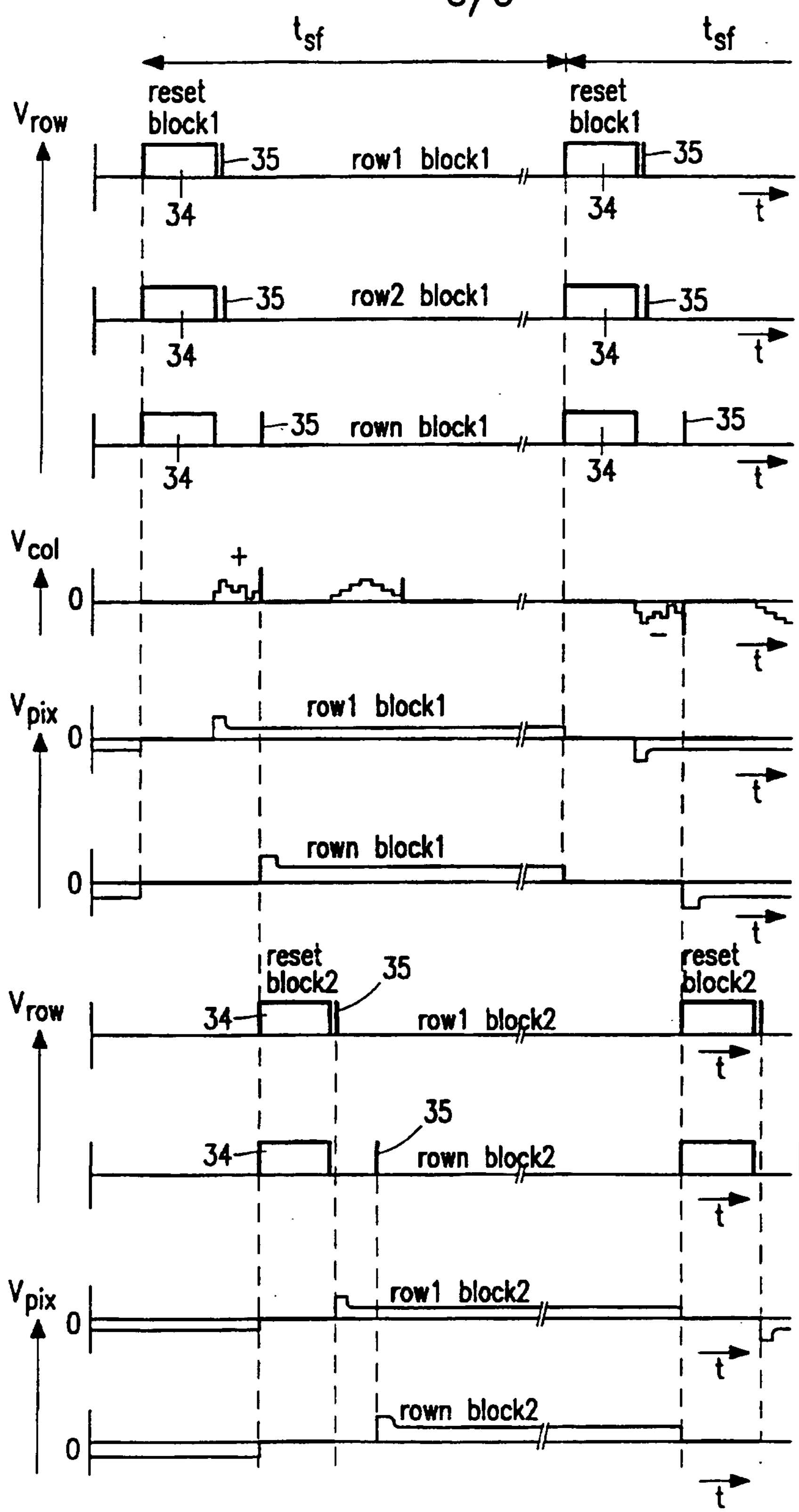

FIG. 8a FIG. 8b FIG. 8c FIG. 8d FIG. 8e FIG. 8f FIG. 8g FIG. 8h FIG. 8i FIG. 8j